



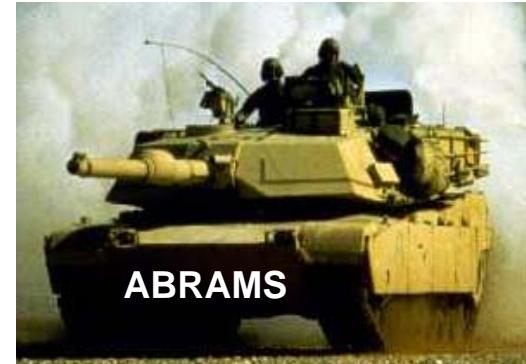
U.S. Army Benet Laboratories

# Hard Chrome Alternatives Team

## 20-21 July, 2004, Utah



### Elimination of Chromium Electrodeposition from Large Caliber Launch Systems



Name of Briefer: Krystyna Truszkowska  
US Army Benet Laboratories

*part of the US Army Armaments Research, Development  
and Engineering Center*



## Report Documentation Page

*Form Approved  
OMB No. 0704-0188*

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE <b>JUL 2004</b>	2. REPORT TYPE	3. DATES COVERED <b>00-00-2004 to 00-00-2004</b>		
4. TITLE AND SUBTITLE <b>Elimination of Chromium Electrodeposition from Large Caliber Launch Systems</b>			5a. CONTRACT NUMBER	
			5b. GRANT NUMBER	
			5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)			5d. PROJECT NUMBER	
			5e. TASK NUMBER	
			5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Army Benet Laboratories, Picatinny Arsenal, NJ, 07806</b>			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR'S ACRONYM(S)	
			11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>				
13. SUPPLEMENTARY NOTES <b>24th Replacement of Hard Chrome Plating Program Review Meeting, July 20-21, 2004, Park City, UT. Sponsored by SERDP/ESTCP.</b>				
14. ABSTRACT				
15. SUBJECT TERMS				
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>20</b>
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>		



# LARGE CALIBER GUN EROSION

*Direct Fire*



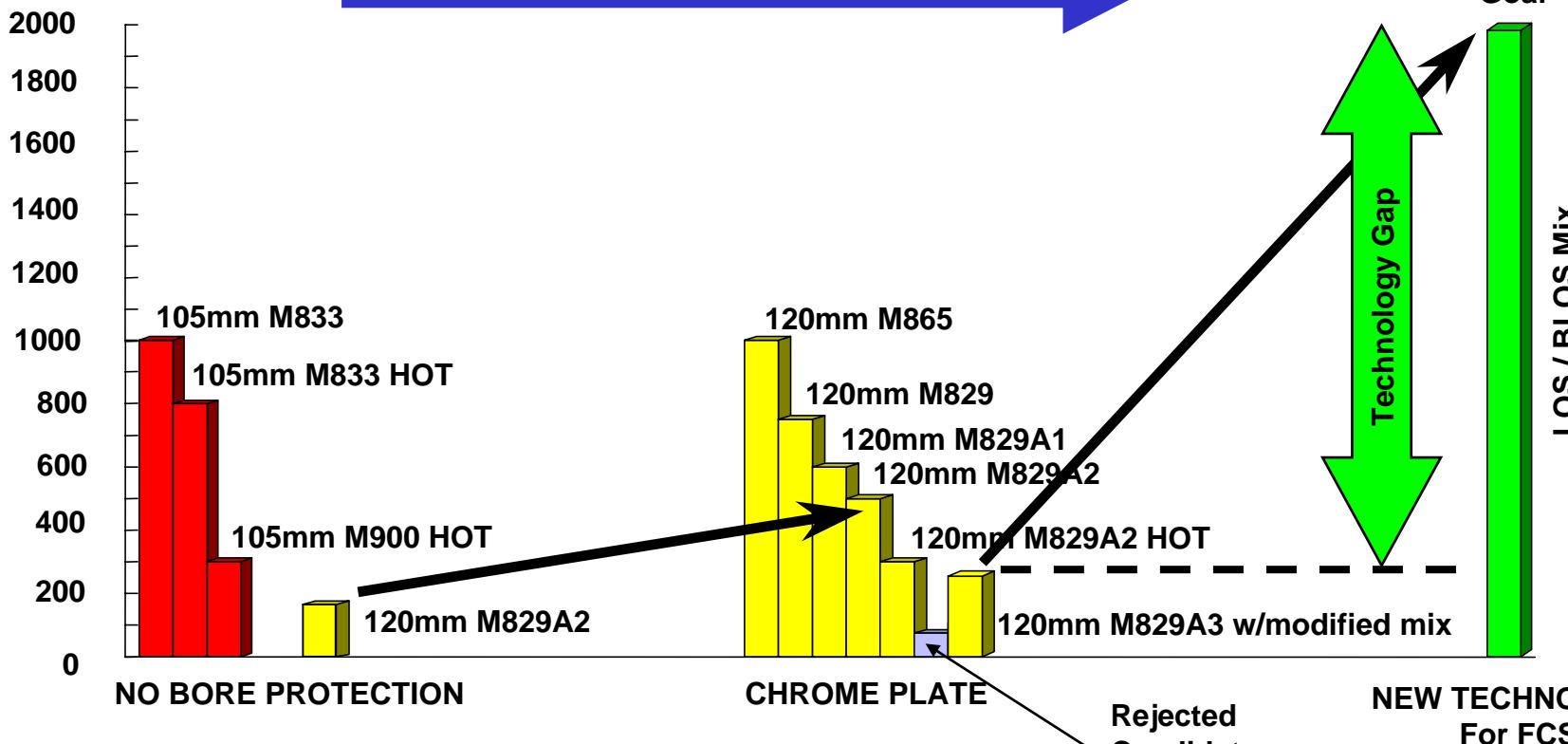
ARDEC

U.S. Army Benet Laboratories

BARREL  
CONDEMNATION  
(RNDS)

**INCREASING MUZZLE ENERGIES REQUIRE:**  
*Improved Bore Protection*  
*Less Erosive Energetics*

FCS-Mounted  
Combat System  
Goal



Executive Order 13148 "Greening The Government ....."

Reduction of Toxic Chemical Releases by 40% by 31 Dec 2006

Reduction of Toxic Chemical Usage by 50% by 31 Dec 2006

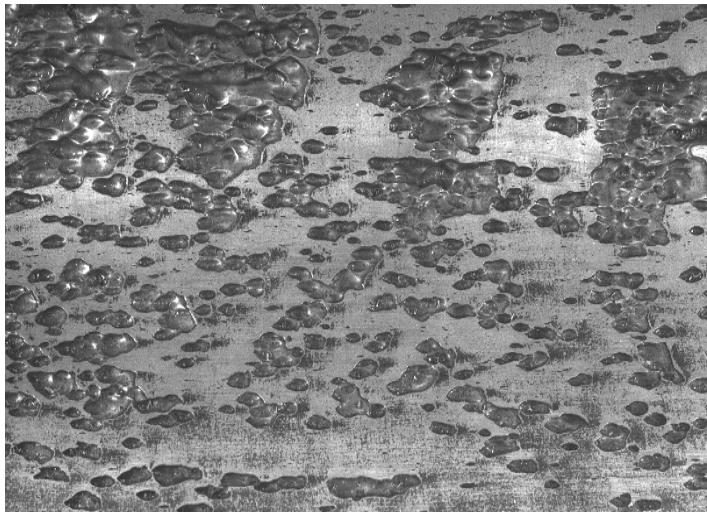


# 120mm GUN BARREL DEGRADATION

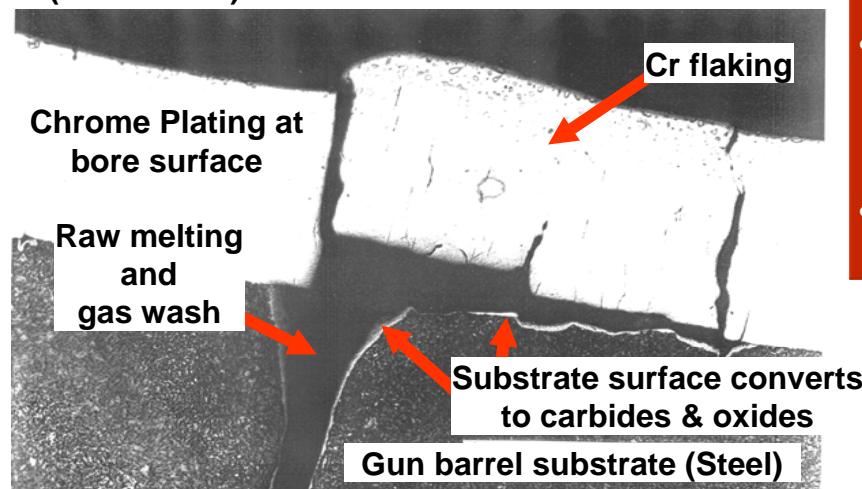
## Classic Erosion Defined



U.S. Army Benet Laboratories



Condemned ABRAMS 120mm GUN BARREL  
(214 rounds) : > 5mm erosion

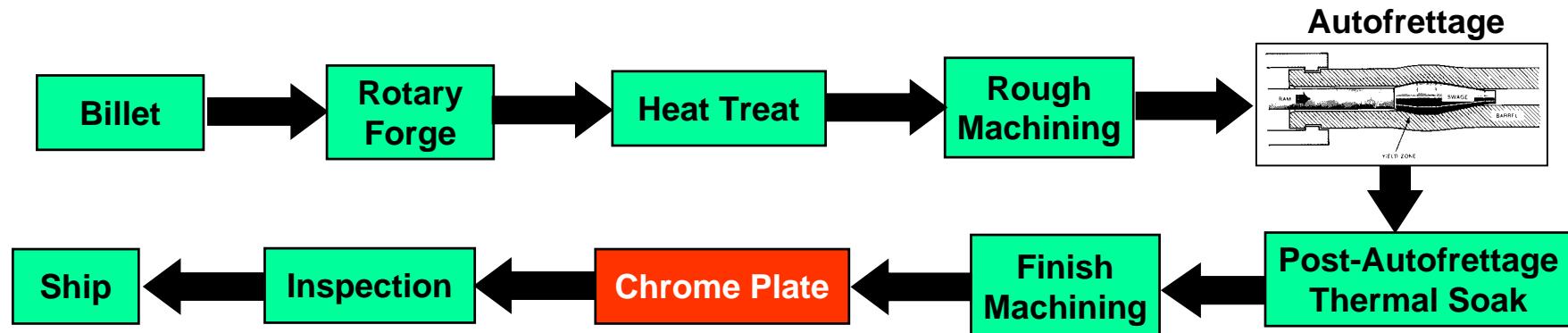


- HC Chrome is produced in an “as cracked” condition offering path to substrate
- HC Cr contaminants off-gas causing further material volume shrinkage and stress-relief cracking
- Combustion products:
  - Penetrate cracks
  - Alter steel substrate phase
  - Convert substrate surface to carbides & oxides
  - Lowers MP of substrate surface
- Gas wash:
  - Removes lower MP substrate surface
  - Erodes Cr foundation (compromised adherence)
- Departing Cr exposes more substrate to high velocity gas wash and further erosion



U.S. Army Benet Laboratories

# 120mm GUN BARREL MANUFACTURING PROCESS



Rotary Forging



Machining



Chrome Plating



Fielding



U.S. Army Benet Laboratories

# LARGE CALIBER GUN COATING REQUIREMENTS



## Material & Deposition Process Requirements

### MATERIAL CHARACTERISTIC

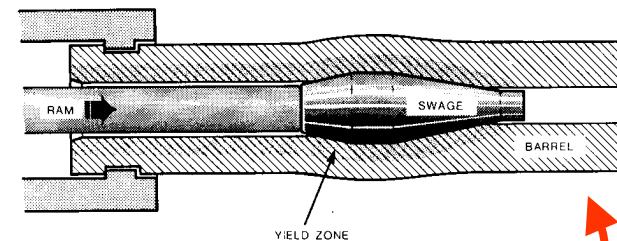
<b>Melting Point</b>	<i>Cr (1875 C) or better</i>
<b>Elastic Modulus</b>	<i>Compatible with substrate (facilitates low surface crack densities)</i>
<b>YS at Elevated Temps</b>	<i>High</i>
<b>Fracture Toughness</b>	<i>High</i>
<b>Hot Hardness</b>	<i>High (appropriate)</i>
<b>Chemical Resistance</b>	<i>High</i>
<b>Coefficient of Thermal Exp.</b>	<i>Compatible with substrate</i>
<b>Thermal Conductivity</b>	<i>Low</i>
<b>Reaction w/ Rotating Band</b>	<i>Inert</i>
<b>Phase Transformations</b>	<i>None</i>

### CRITERIA

### PROCESS CHARACTERISTIC

<b>Deposition Temperature</b>	<i>Less than 357C (post autofrettage thermal soak limit)</i>
<b>Deposit Rate</b>	<i>1 mil of coating material per hour</i>
<b>Surface Finish</b>	<i>Equal or better than 32 RMS at deposition</i>
<b>Deposition Length</b>	<i>58 Calibers or greater</i>
<b>Hazardous Impacts</b>	<i>None or limited</i>

### CRITERIA





U.S. Army Benet Laboratories

# COATING DEPOSITION PROCESS SELECTION

for *Large Caliber Guns*



ARDEC

FUNCTIONAL REQUIREMENTS	PROCESS								
	Molten Salt	Plasma Spray	Chem. Vapor Dep.	Ion Implant.	Ion Plate	Explosive Bonding	Metal Cladding	Aqueous Electro-Dep	Cyl Magnetron Sputtering
Autofrettage Stresses Protected				✓	✓			✓	✓
No Post-process Surface Finish Req	✓			✓		✓	✓	✓	✓
Acceptable Deposition Rate	✓	✓	✓			✓		✓	✓
Proper Process Aspect Ratio				✓				✓	✓
Accept Dim. and Densities over 50 cal								✓	✓
Acceptable Adhesion	✓					✓		✓	✓
Dry Process		✓	✓	✓	✓	✓	✓		✓
Eliminate Hazardous Materials				✓	✓	✓			✓
Eliminate Air / Water Contamination				✓	✓	✓			✓

•TECHNICAL PANEL EXPERTS (1997)



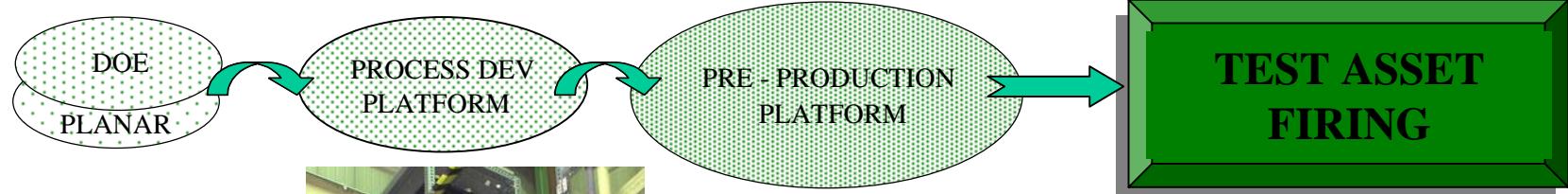
# TECHNICAL APPROACH

## *Technology Maturation Methodology*

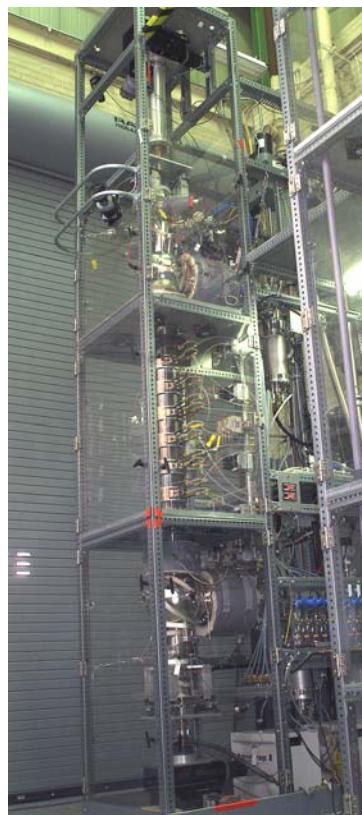


U.S. Army Benet Laboratories

ARDEC



Coupons &  
12" Sections



40" Sections



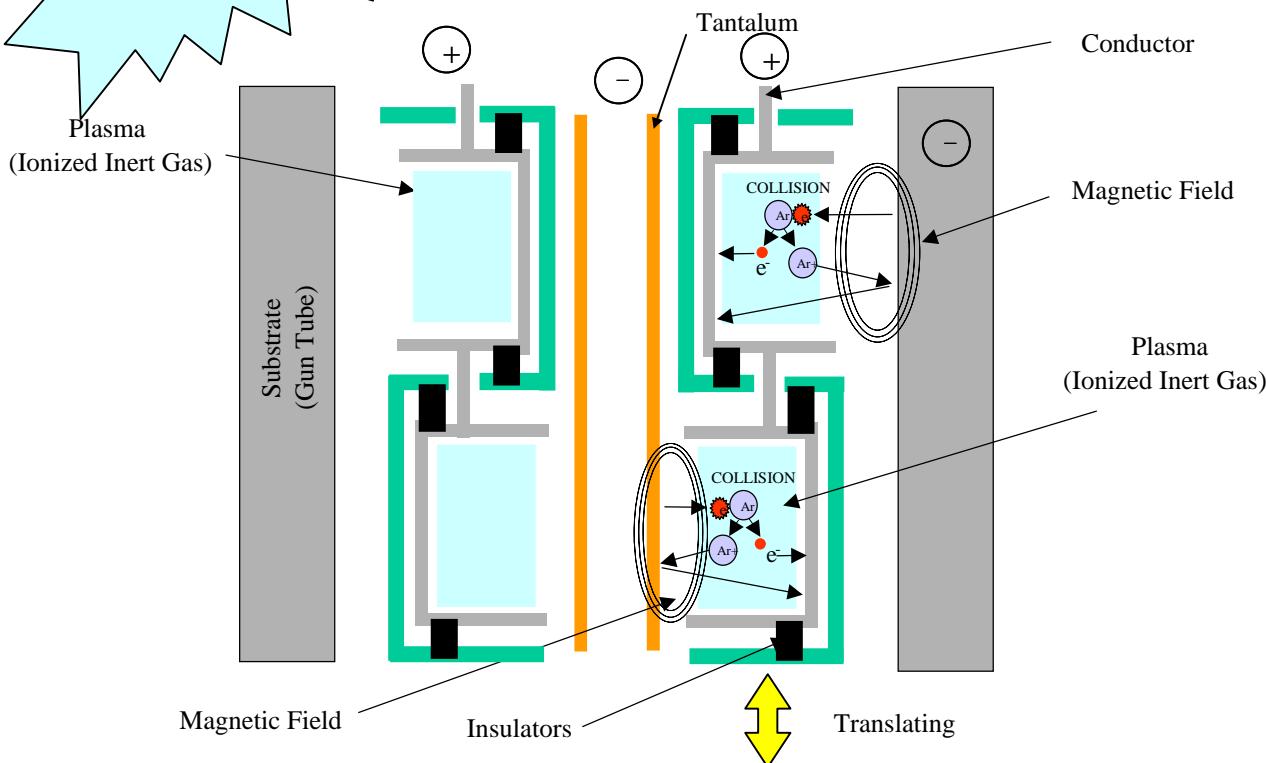
Full-Length Gun Barrels



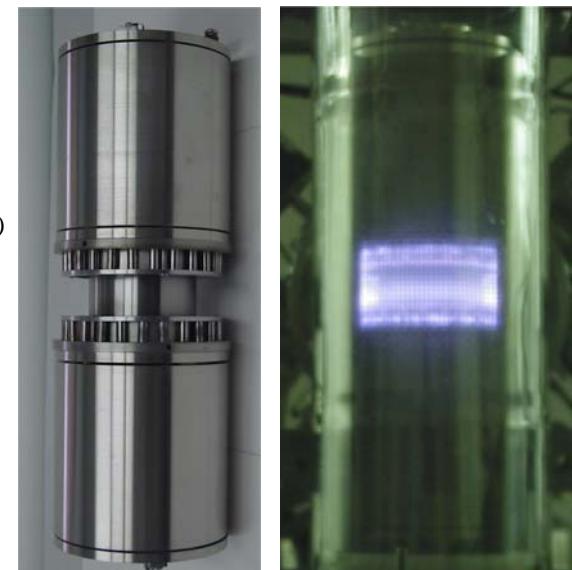


# BENET SIGNIFICANT ACCOMPLISHMENTS

## *Lg Cal Plasma Cleaning Device (PCD)*



ARMY PATENT PENDING  
Disclosure No. 2002-020



Lg Cal PCD Substrate Cleaning  
w/PCD

An Army patent pending manufacturing technology to provide “atomically clean” surfaces for CMS deposition onto full length gun barrels

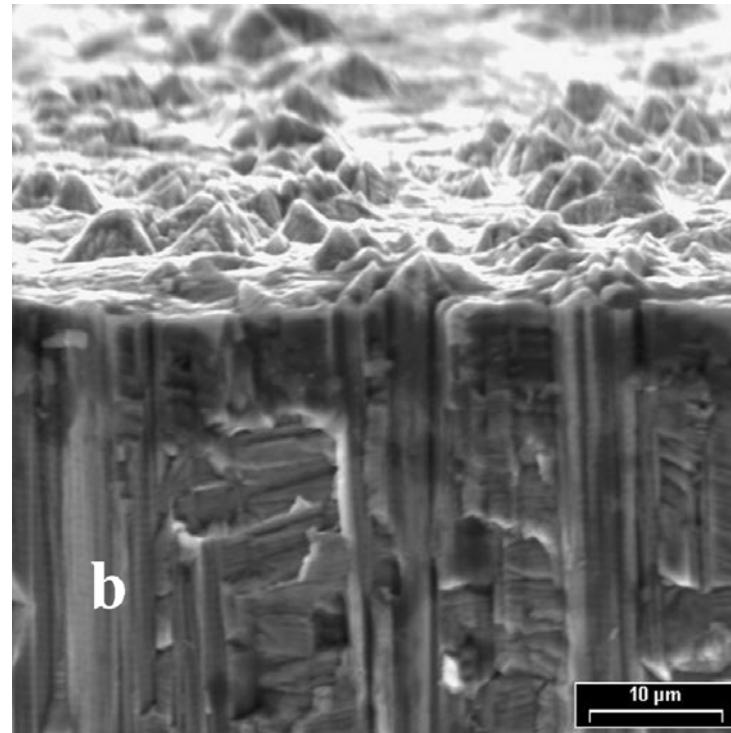
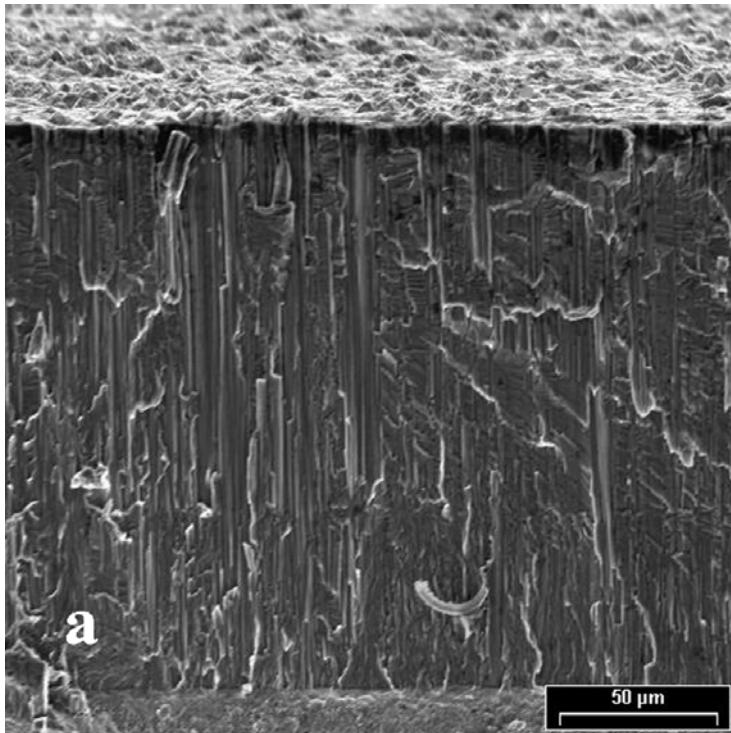


U.S. Army Benet Laboratories

# CMS Cr Coating Morphology



ARDEC



- SEM images of tensile fractured chromium specimens:
  - a: dense fibrous grain structure (zone T per Thornton)
  - b: small amount of columnar growths
- XRD residual stress study: compressive stress of ~ 30 ksi



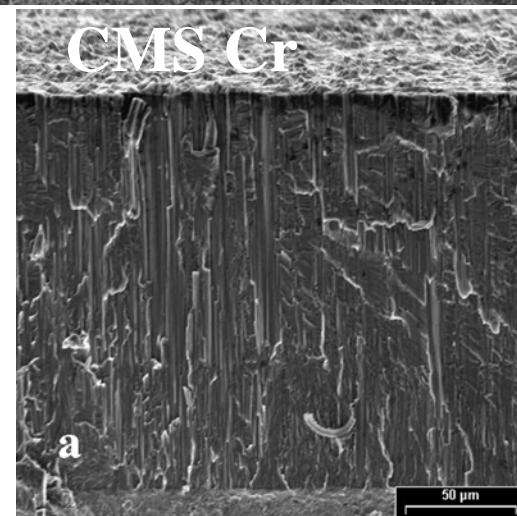
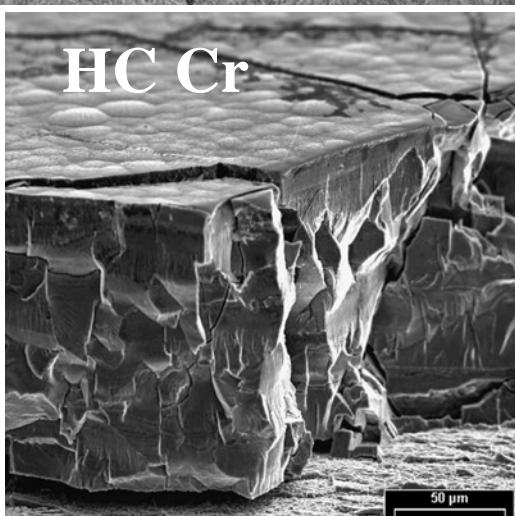
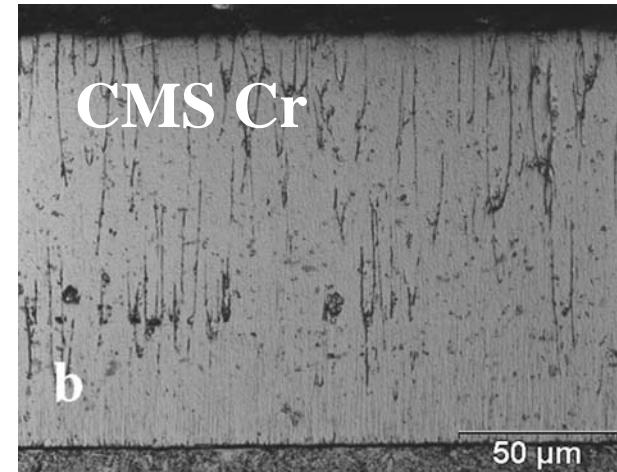
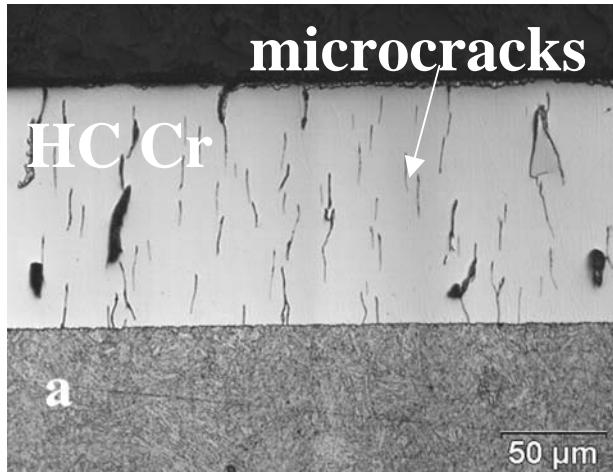
U.S. Army Benet Laboratories

# Cr Coating Comparison

*Electroplated vs sputtered*



ARDEC



Microhardness:  
HC Cr  
CMS Cr

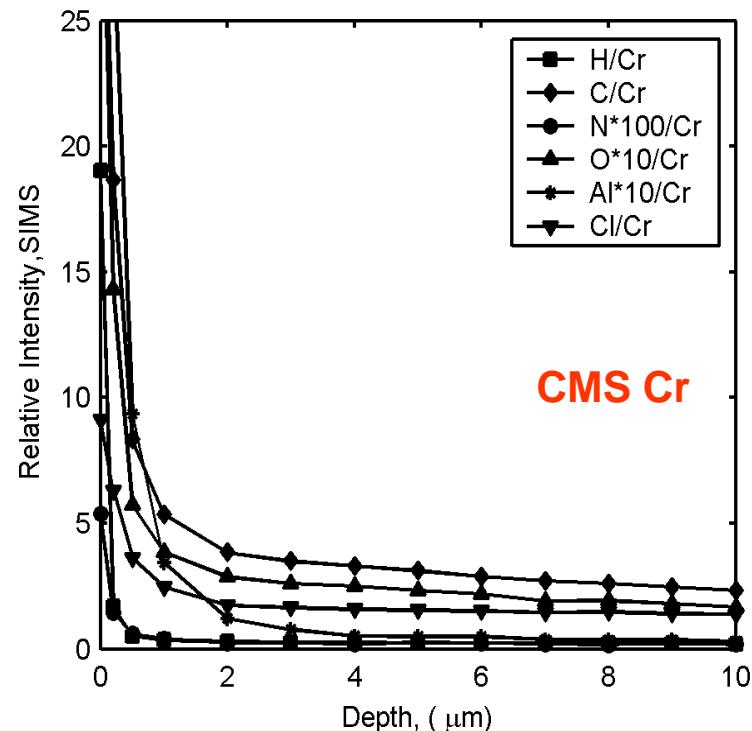
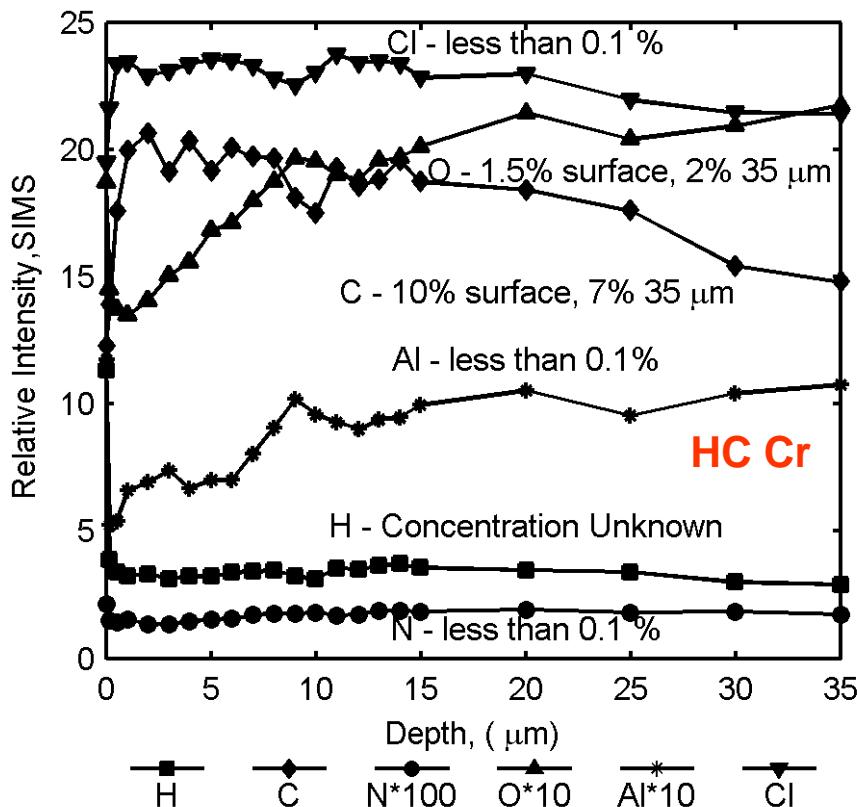
800-1000 HK  
220 - 400 HK



U.S. Army Benet Laboratories



# Cr Coating Composition



## SIMS peak intensity vs profile depth

Bulk impurity concentration:

- CMS Cr: all non-Cr elements < 0.1 at %
- HC Cr: carbon concentration  $\sim$  10 at %, oxygen concentration  $\sim$  2 at %



U.S. Army Benet Laboratories

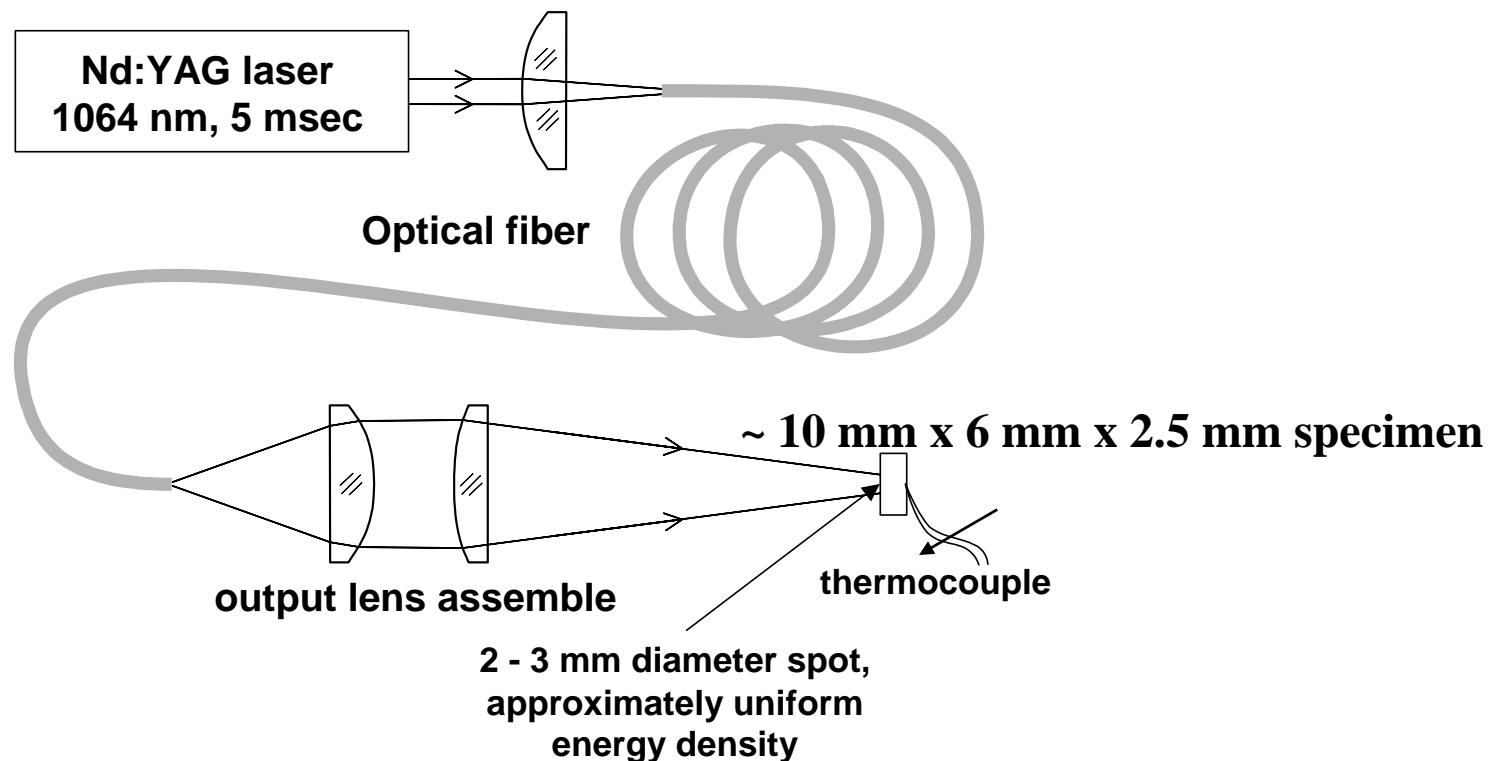
# Coating Evaluation Process

## Adhesion and Erosion Rate



## Laser Pulse Heating (LPH) method

*Thermal shock resistance*



P. Cote et al, Surf. Coat. Technol. 163-164, 2003



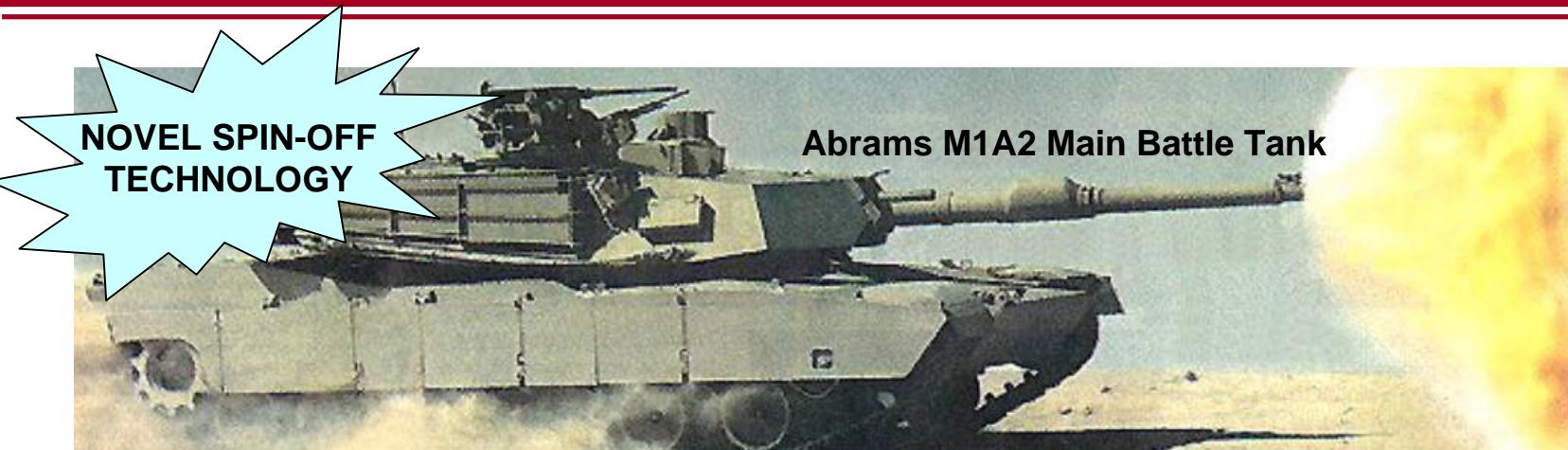
# Coating Evaluation Process Cont.

## Adhesion and Erosion Rate



U.S. Army Benet Laboratories

ARDEC



Abrams M1A2 Main Battle Tank

## Vented Erosion Simulator (VES): *For Interim Coatings Validation*

- Flame T & chemistry similar to M829A2/M829A3
- Accepts Lg Cal coated coupons
- Extensively modeled
- Does not exceed critical T observed in current gun barrel erosion process
- Used to screen, evaluate, optimize, and validate Lg Cal gun bore coatings



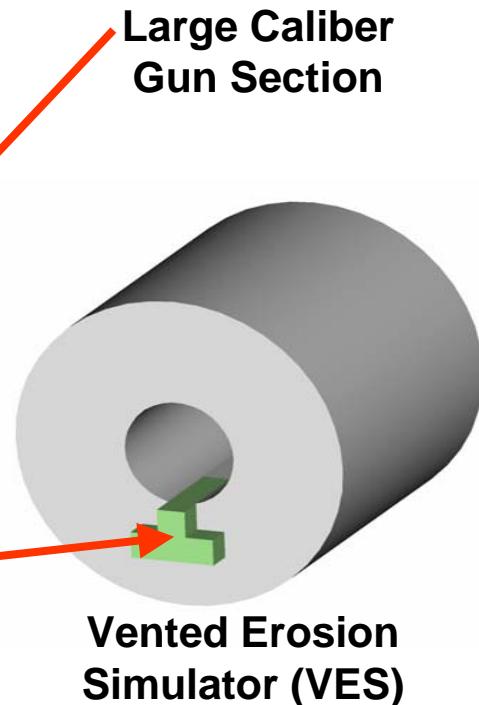
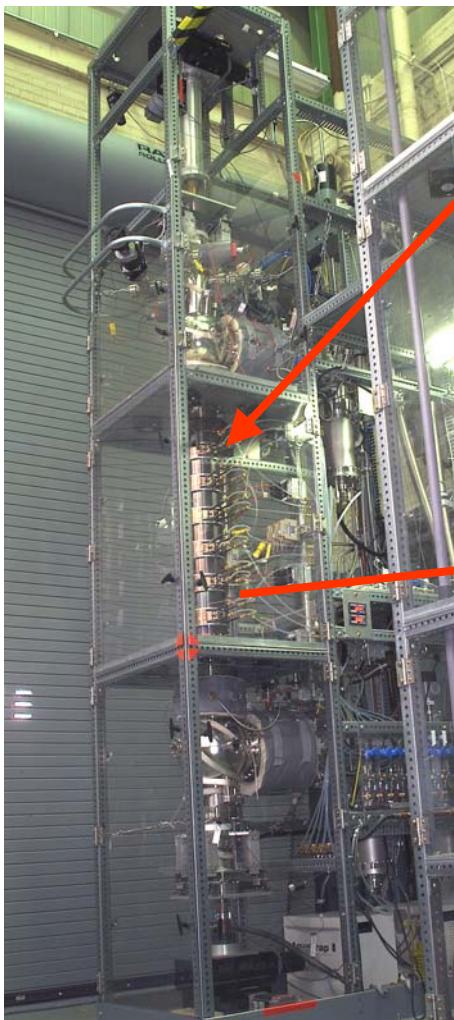
Benet's VES evaluates coatings in a simulated  
Lg Cal Gun Firing Environment



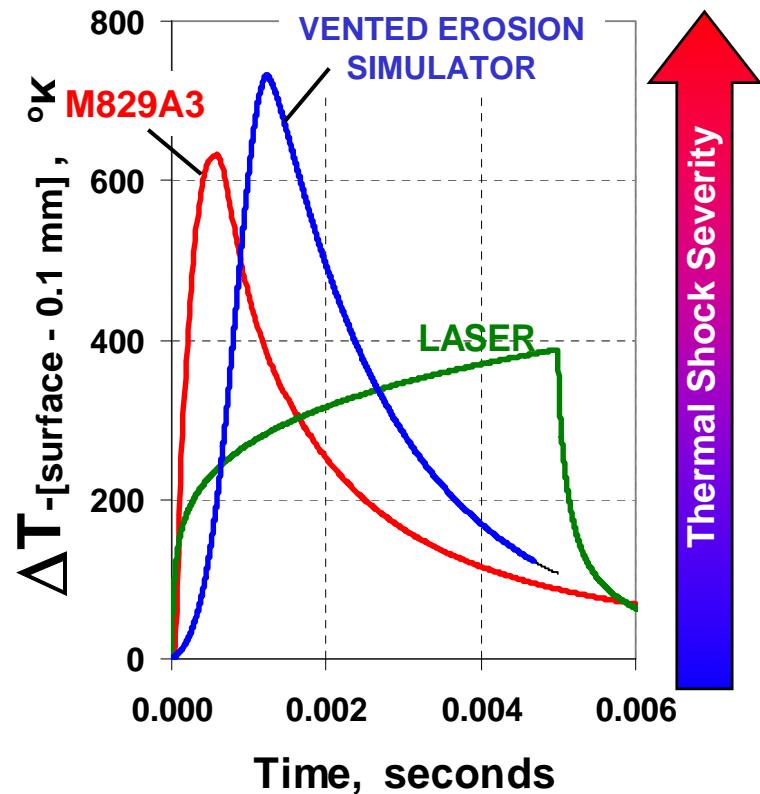
U.S. Army Benet Laboratories

# INTERIM COATINGS VALIDATION

## Vented Erosion Simulator (VES) Testing



- Flame T & chemistry similar to M829A2/M829A3
- Accepts Large Caliber coated coupons (*eliminates process scaling*)
- Ballistically modeled & validated
- Substrate transformed to same depth as Lg Cal Gun
- Maintains critical T observed in current gun barrel erosion process





U.S. Army Benet Laboratories

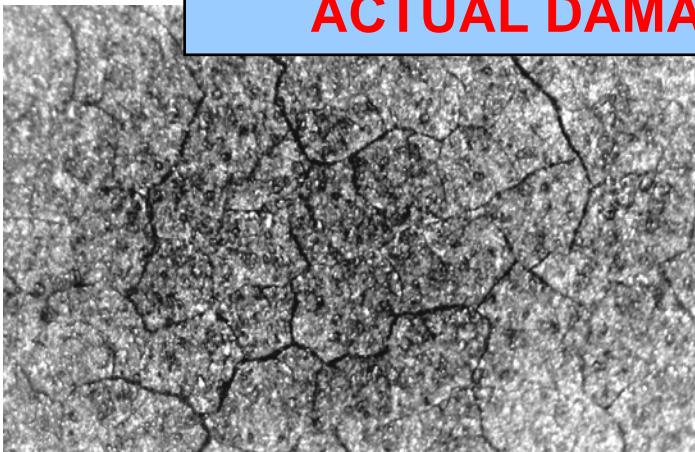
# VENTED EROSION SIMULATOR (VES)

*an excellent simulation of Lg Cal gun firing*



ARDEC

## ACTUAL DAMAGE FROM M829A3 FIRINGS



Top View – Thermal shock cracking

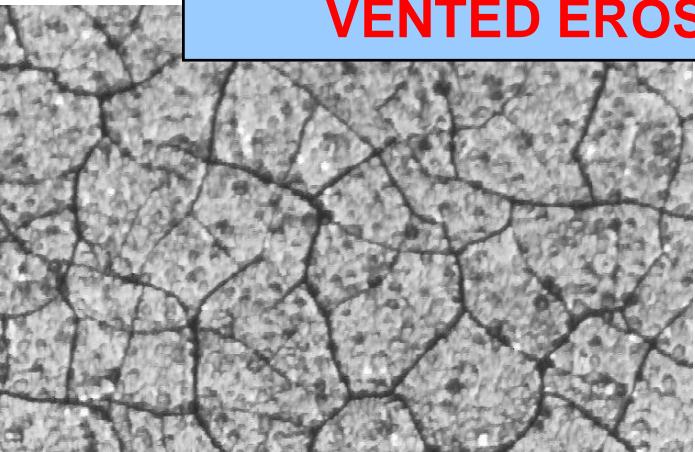


HC Cr coating

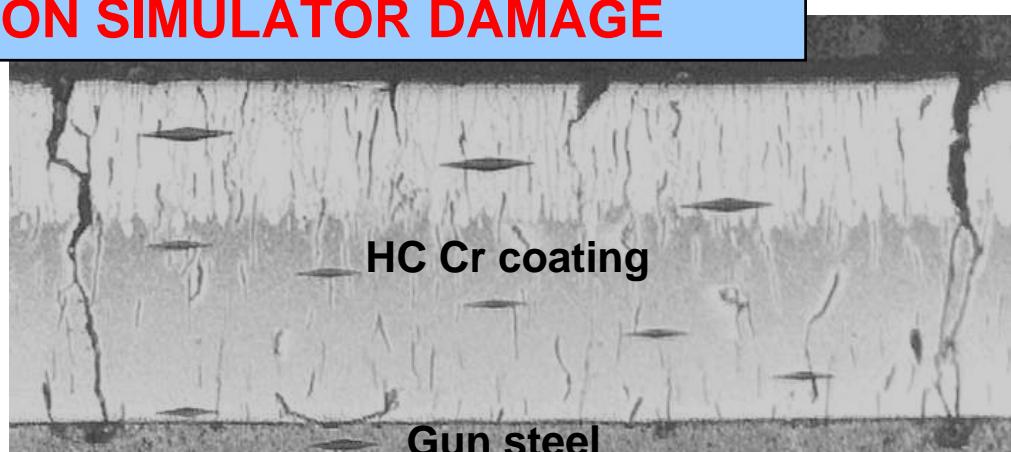
Gun steel

X-Section – Cracking, HAZ, thermo-chemical attack

## VENTED EROSION SIMULATOR DAMAGE



Top View – Thermal shock cracking



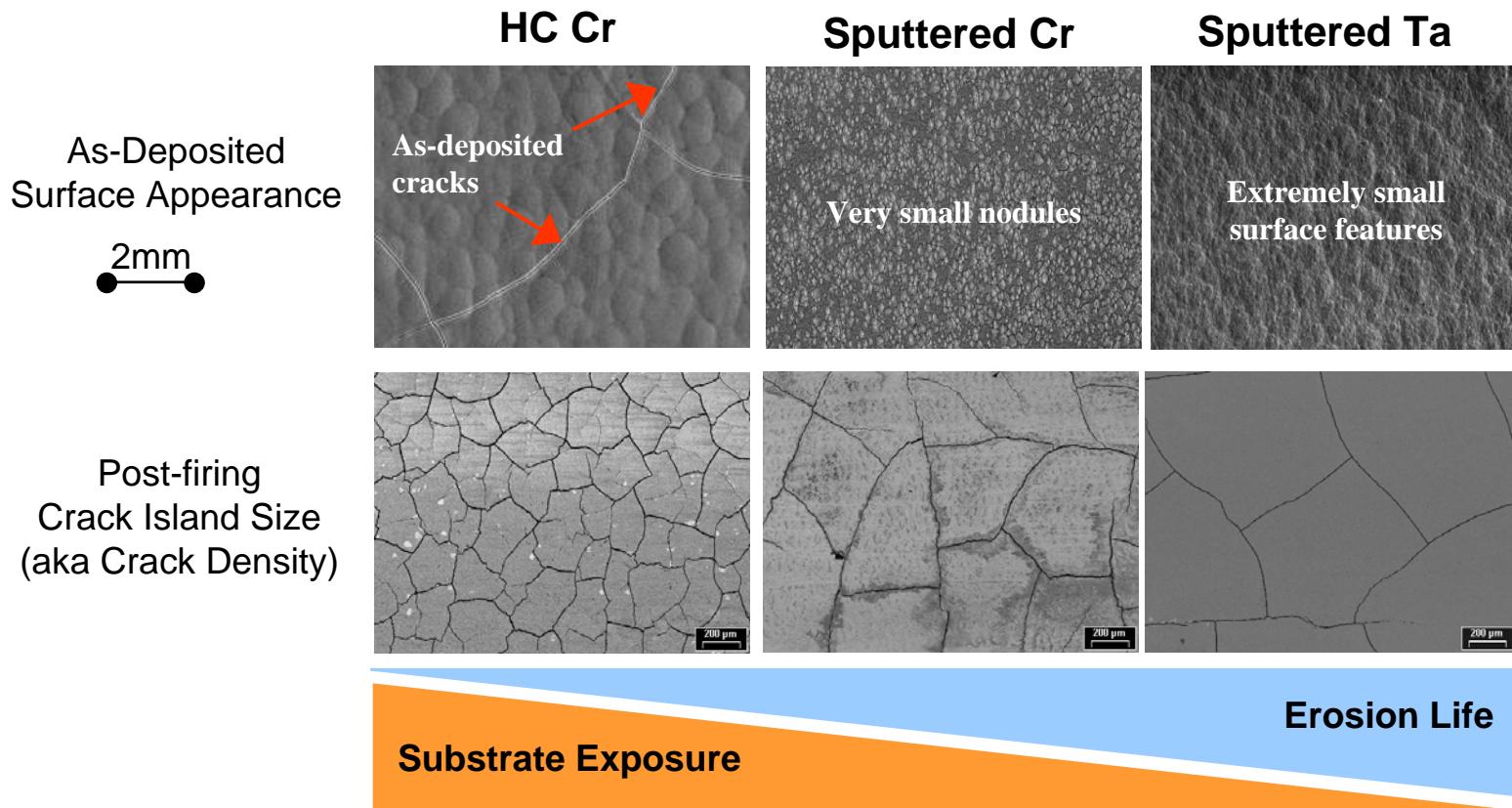
HC Cr coating

Gun steel

X-Section – Cracking, HAZ, thermo-chemical attack

# COATING CRACK DENSITY

## *Substrate Exposure – Erosion Rate*



**Erosion Life**

**120mm Tank Gun Surfaces**



U.S. Army Benet Laboratories

## Summary of

# TECHNICAL METRICS

## Advanced Coatings for Large Caliber Guns



CHARACTERISTIC	Current state of HC CHROME PLATING	Desired end state for SPUTTERING	VERIFICATION TECHNIQUE	CURRENT STATUS
Coating Morphology	Zone 2	Zone 2	Microscopy	yes
Coating Phase	Single	100% Alpha (Ta) bcc (Cr)	Microscopy	yes
Hardness	900 -1100 Knoop	200 - 300 Knoop	Microhardness (Ta) Microhardness (Cr)	yes
Thermal Shock Resistance	Poor	Excellent	Pulsed Laser Vented Erosion Sim	yes
Adhesion / Cohesion	Excellent	Excellent	Groove Testing VES (Ta) VES (Cr)	yes
Distribution over Length	.002 - .006 in.	Less than .0005	Microscopy	yes (80")
Distribution around ID	.002 - .006 in.	Less than .0005	Microscopy	yes
Deposition Rate	.001 inches/hr	.001 inches/hr	Microscopy	no (.00075)
Coating Thickness	.002 - .006 in.	.004 - .006 in.	Microscopy	yes
Surface Finish	63 finish	32 or better	Visual	yes (16)
Onset of Erosion	100 VES shots	better	Visual / Microscopy	yes
Weapon Service Erosion Life	260 Rnds (M829A3)	400 Rnds (M829A3)	Firing Tests	TBD



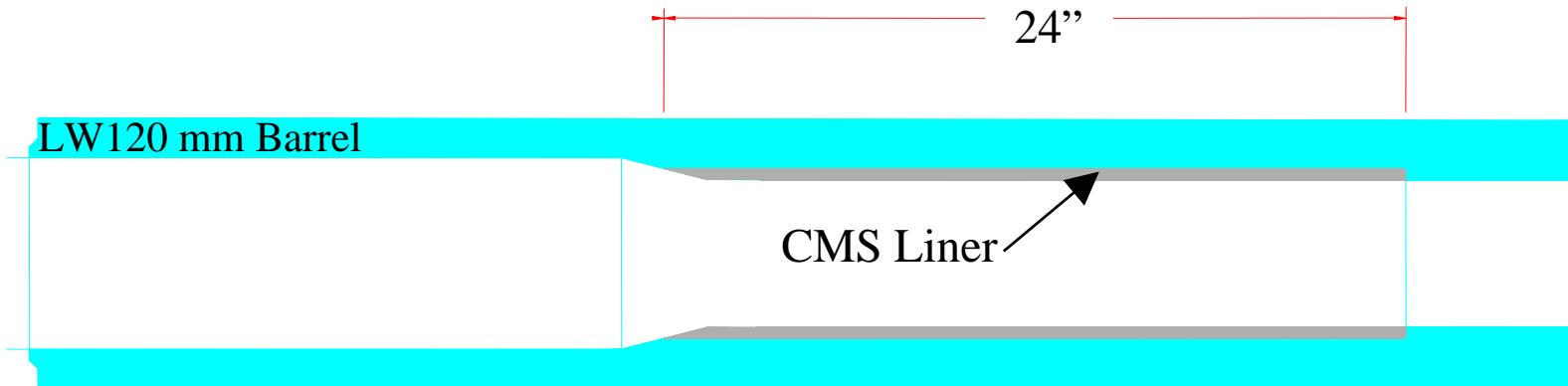
# UPCOMING FIRING DEMONSTRATIONS

## *Advanced Sputtered Coatings*



U.S. Army Benet Laboratories

ARDEC



### 120mm XM36 Firing Test #1

- 120mm coated, shrink-fit liner
- July 04

### 120mm XM36 Firing Test #2

- 120mm coated, shrink-fit liner
- Oct-Nov 04

### 120mm XM36 Sub-Scale Development & Testing

- Full-length monoblock coating test
- Mid FY05



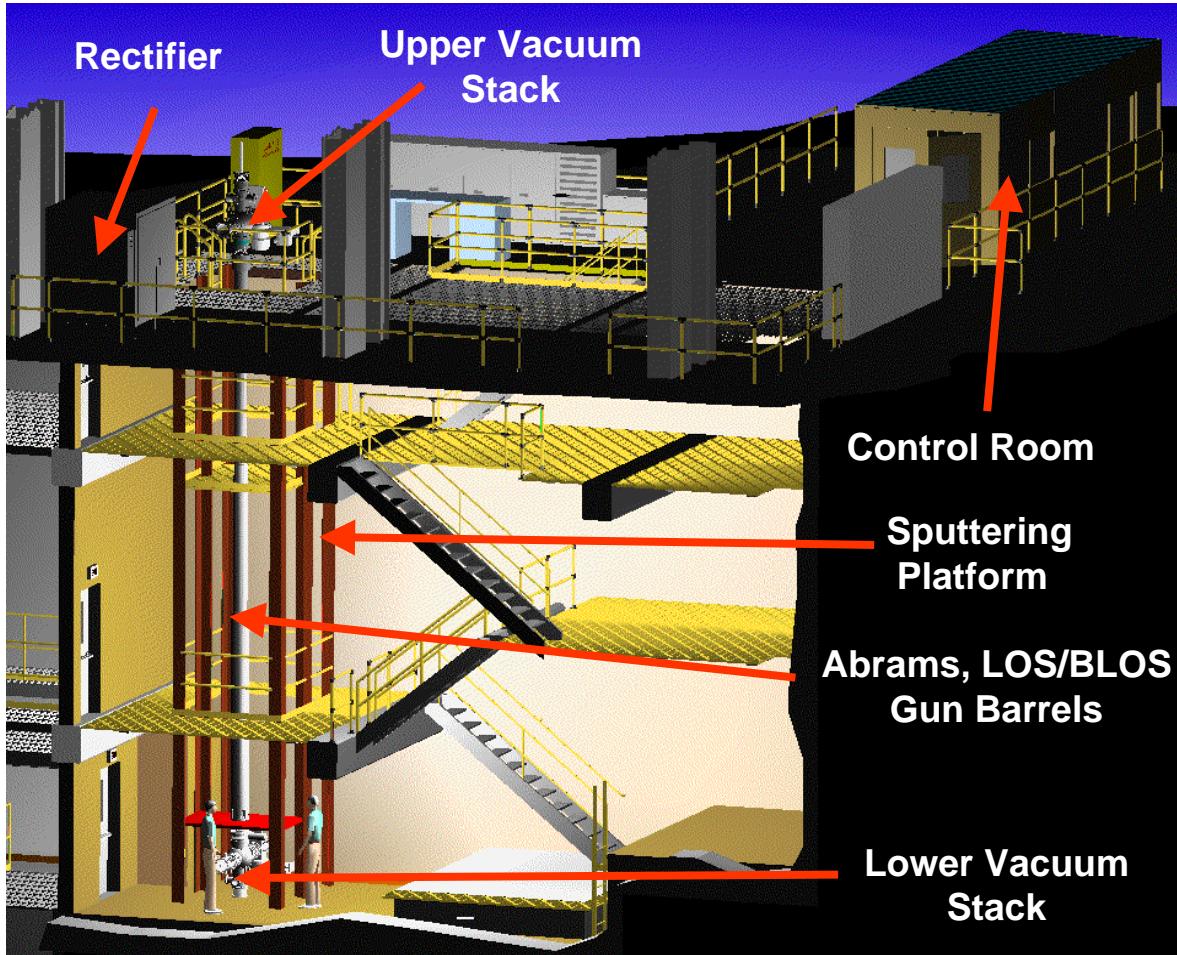


**BENET**  
Labs

U.S. Army Benet Laboratories

# LARGE CALIBER Pre-PRODUCTION Demonstration Platform

*at Watervliet Arsenal – Initial Testing - Sep 04*





U.S. Army Benet Laboratories



# SUMMARY

- **Cylindrical Magnetron Sputtering is a viable alternative to electrodeposition**
- **Cylindrical Magnetron Sputtering results encouraging for large caliber systems**
  - Increased adhesion and bulk properties
  - All laboratory metrics achieved (*still improving deposition rate*)
- **Current 120mm XM36 tests should be insightful**
- **Large Caliber Full-length Pre-Production Platform Initial Testing by Sep 2004**
- **Will one coating technology address all platforms ???**
  - Large Cal vs. Med Cal
  - Autofrettaged vs. Non-Autofrettaged
  - Smoothbore vs. Rifled bore